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RESEARCH PAPER

Use of Smartphone Technology for Small-Scale Silviculture: A Test of Low-Cost Technology in Eastern Ontario

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Abstract This study examined the potential use of low-cost consumer-grade smartphone technology to perform and improve field data collection in support of small-scale forest management. This proof-of-concept exercise for day-to-day forester operations focused on the effectiveness of the smartphone platform (form factor and functionality) rather than any particular smartphone software. An electronic data acquisition system for a smartphone was developed that combined a simple custom timber cruise application and mobile commercial mapping software to record and process forest stand and geospatial information, and transfer these to a small-scale operator's existing desktop geographic information system. Workflow efficiency and system performance of the smartphone system was then measured and compared with paper-based methods presently being used in the managed forest. The smartphone greatly increased workflow efficiency by reducing data transfer and processing times, and eliminated the need to carry separate global positioning system (GPS) device, map, paper forms and digital camera. The GPS accuracy of the smartphone was more than adequate to meet operational requirements, and provided a capacity to map forest features on an ad hoc basis that is not easily done through the paper-based process. However, initial data entry using the smartphone takes longer than using paper-based notes, there is a greater chance of data entry error through inadvertent keypad touches on the small screen, and there is the potential for a device malfunction. Overall, it is concluded that smartphones offer an opportunity for small-scale operators to create electronic field data management systems that are affordable, operationally robust, compatible with existing

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management systems, capable of increasing data management efficiency and, in particular, expanding the types of data that can be collected during silvicultural operations.

Keywords Mobile phone · Mobile GIS · Data management · Workflow efficiency · Paperless

Introduction

In Ontario, Canada, as in many other jurisdictions, government regulations require forestry companies to conduct primary data collection and maintain electronic records of forest resources, management and planning activities. Such data include: the density, distribution, species, age and size classes of trees by stand; information concerning forest disturbances; details of cultural heritage resources, and endangered or protected species; location of areas or features of concern (e.g. watercourses); and other forest attributes. To capture and record these geospatial and attribute data, small-scale forestry operators in eastern Ontario typically use paper-based data entry forms and a variety of other tools including paper and digital maps, survey instruments, aerial imagery, digital cameras and global positioning system (GPS) devices. Capturing and managing these data can be time consuming, expensive and error prone, particularly given the need to manually transfer data from paper-based forms into electronic spreadsheets and GIS software upon return to the office (as also observed by Longley et al. 2005; Inman-Narahari et al. 2010). Government-imposed data reporting regulations apply to all operators regardless of size, placing smaller forestry companies and harvesters working on private land at a competitive disadvantage as compared with larger forest companies (see also Bernard and Prisley 2005).

Data loggers, GPS devices, digital cameras and other electronic devices increase the amount of data that can be collected by forest operators, and researchers and private companies are continually developing new tools such as customized personal data assistants (PDA) and proprietary software to assist forest managers (e.g. Li and Wang 2009; Zhou et al. 2009; Yao and Li 2010; Li and Jiang 2011). Such tools can be expensive, and unless they are fully integrated with pre-existing data management processes, the need to compile the data from multiple sources and organize them manually creates administrative work that draws time away from operational activities. These are important considerations for small-scale forestry operations.

An alternative option may be an electronic data collection and management device most forestry workers already carry in their pockets—the mobile phone. The use of mobile phones capable of running computer applications (apps)—hereafter referred to as ‘smartphones’—for data collection is continually expanding in many industries, and has proven to be highly successful for field use in epidemiological studies, air quality measurement and traffic monitoring, to name just a few applications (e.g. Honicky et al. 2008; Aanensen et al. 2009; Herrera et al. 2010). Current generation smartphones costing less than $200 CDN possess integrated sensors allowing the device to include a range of features (e.g. digital compasses, accelerometers, gyroscopes and light meters), to act as global positioning (GPS) receivers, and to run software that processes geospatial information in ways

comparable to more expensive computing devices (Kwok 2009). They have become so relatively inexpensive and ubiquitous that in many businesses and industries, employees now use their personal smartphones for work and private use (Walker-Osborn et al. 2013).

No previous studies were uncovered in the literature that tested the smartphone platform, form factor and capabilities for data collection in small-scale forestry operations. To address this gap, a study team was formed, which consisted of GIS scholars and a professional forester, to develop and test a field data collection and management system using an off-the-shelf GPS-enabled smartphone and off-the-shelf mobile geospatial data collection software (ArcPad) designed to connect and integrate directly with the existing GIS-based data system being used by a small-scale forest company. The system was designed specifically to collect timber-cruise and forest resource data as required under an Ontario Sustainable Forest License agreement held by a small commercial forest management company, Mazinaw-Lanark Forestry Inc. of eastern Ontario. The system was put through field and semi-controlled initial feasibility tests to evaluate the smartphone performance, efficiency and accuracy.

The timing of this research is important given the degree to which smartphone technology has permeated almost all aspects of day-to day-operations. Smartphones are pervasive and that fact presents a natural opportunity to assess how this technology can be leveraged within small-scale forestry operations. By testing the smartphone platform and its data collection capabilities, this research is fully generalizable to any other instance of a smartphone platform employing any instance of a mobile spatial data collection system.

In designing this project, some key considerations particular to small-scale forestry as well as rapid assessment of the smartphone platform shaped decisions with respect to choice of hardware and software, and the overall architecture of the system, including:

- the desire to use low-cost, off-the-shelf hardware and software wherever possible;
- ability of the smartphone to connect and integrate into existing data collection and management systems, and not require the creation of additional tasks or systems;
- capacity to operate successfully and collect data in the rough terrain and variable weather conditions of the forest, and in areas where wireless internet and cellular connectivity are absent;
- and, minimal need for customization of software in order to assess rapidly the smartphone platform and capabilities.

Research Method

The research method sought to create a realistic comparison between an existing paper-based data collection and management system and one that used a smartphone as the data collection and processing device to perform the same tasks. In designing the

smartphone-based system, it was important that the smartphone be able to replicate the main steps in the present workflow system being used by the test small-scale forestry enterprise, Mazinaw-Lanark Forestry of Cloyne, Ontario. As seen in Fig. 1, the workflow consists of six interconnected steps that are being cycled through on a continuing basis, as described in the boxes labeled 'paper-based method'. In the first step, forest managers planning to enter the field prepare their background data collection tools and identify locations where data collection is to occur. Once in the field, standardized forms are used to collect raw data, such as stand composition, and match these to specific locations. Upon return to the office, these data are transferred into the server system for processing, which involves manual transfer of data into office and GIS software. The forest inventory database and GIS-based maps of the management area are then updated and made ready for analysis.

This project began in late 2010, and was thus constrained by the state-of-the-art smartphone technology available at that time. The basic architecture employed for the smartphone (digital) method shown in Fig. 1 was a one-to-one client–server relationship, where the smartphone (the client hardware) was used to collect GIS data that would be loaded directly into the forest company's existing electronic data management system (the data server) using the check-in and check-out functions[1] of the desktop GIS software. The desktop server-side system was a standard Windows XP system with ESRI ArcGIS 9.3.1 that exchanges content with the client smartphone device via ArcPad, performs GIS and other data processing operations, and maintains the master geodatabase of forestry feature classes. The hardware selected (i.e. the client side) was a HTC HD2 Windows 6.5 smartphone with ArcPad installed that was capable of recording, displaying, editing and storing geospatial data and geotagged[2] photographs using its internal GPS receiver antenna. Communication between the two computing systems took place through a wire universal serial bus (USB) cable and Microsoft ActiveSync 4.5 software.

This particular smartphone was selected because of its large screen display (4.3 inches—large for the time although small by today's standards), internal GPS receiver, built in flash memory card capability, and Windows Mobile 6.5 operating system (OS) (which has since been replaced by Windows Phone 8). That OS was favoured for its ability to run software already being used by the forest company, which included Microsoft Excel and ESRI mobile GIS ArcPad 10.2. The Windows OS also allowed for the creation of a simple customized software application which was found to be essential. An extra battery, stylus, car battery recharger, 32 GB Micro SD card and protective cover were obtained to protect the device and provide additional power and memory storage in the field.

[1] *Check-in/Check-out* is a component of 'versioning' in database terminology. It allows a person to place a local copy of a data layer (for example, the locations of rare trees) onto the smartphone device, go into the field and edit those points, and return to the server computer and upload the newly collected data. Data cannot be changed on the desktop GIS until smartphone-collected modifications are uploaded. Some systems allow for simultaneous changes on the desktop while the data are checked-out, with the two sets of data being later compared with one another for consistency and any changes flagged for manual inspection.

[2] A geotagged photograph is a digital photograph with the GPS coordinates stored internally within the metadata or header section of the digital photo, allowing the photo to be placed on a digital map within a GIS at the location where it was taken.

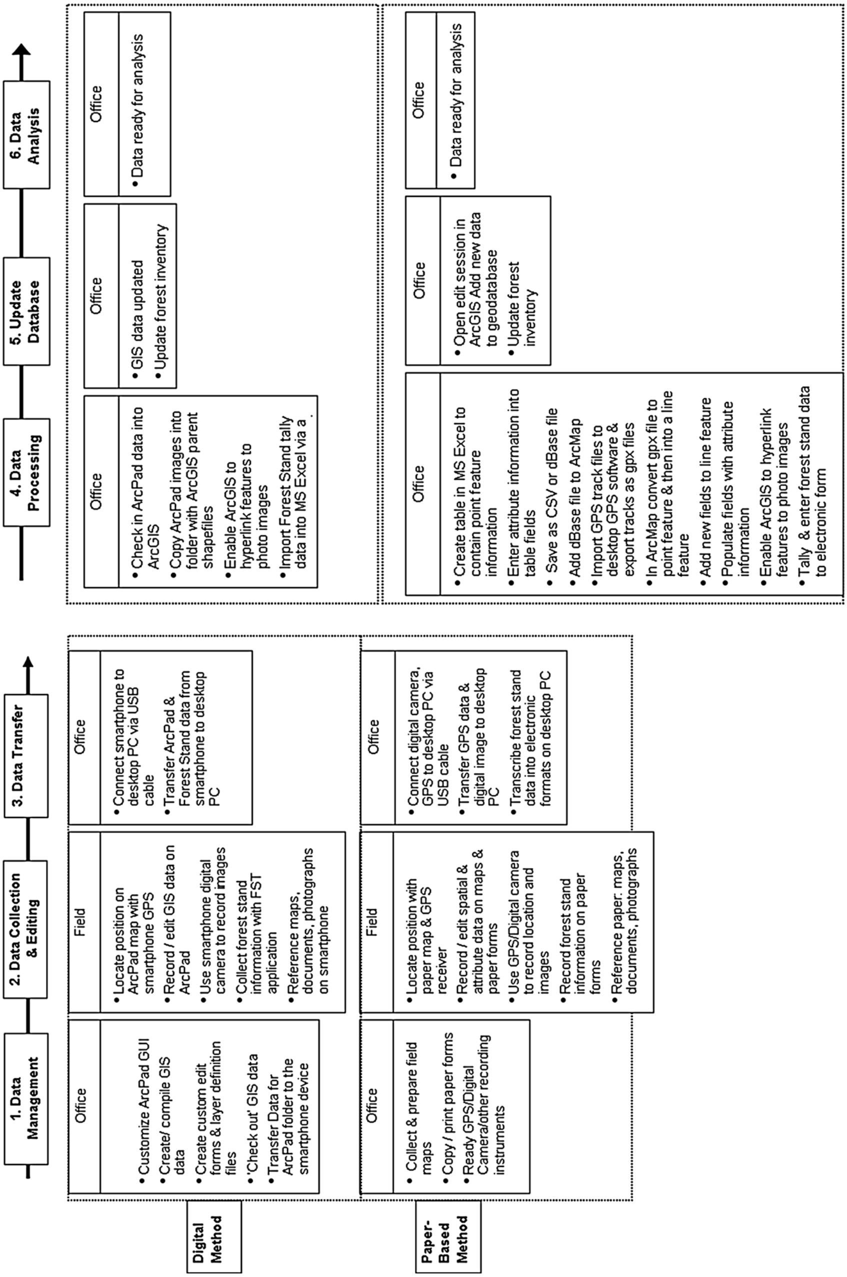

Fig. 1 Study workflow model

Custom mobile GIS development was not required and was out of the question from a time perspective. Quick assessment of the smartphone platform within forestry operations required a means to rapidly develop a data collection system, and this was most easily achieved using commercial desktop and mobile mapping software. If tangible benefits are incurred, then questions of whether to go with commercial software, open source or custom mobile application development become relevant. Given that consideration, of the mobile GIS software available at the time, ESRI's ArcPad 10.2 was selected for its full feature-set, customization capabilities, ability to operate in a disconnected setting (no internet connection required (neither Wi-Fi nor Broadband 2G, 3G, 4G), and its ability to synchronize recorded field data with ArcGIS 9.3.1 for additional cartographic display and spatial analysis.

At the time the project began, neither Apple's iOS nor Google's Android OS contained commercially available mobile apps for custom geospatial mapping and data transfer to desktop GIS, but this is changing, particularly as a number of commercial cloud based and non-cloud based geospatial data collection apps and services have been launched recently, including ESRI's Collector for ArcGIS[3] or GIS Kit Pro for iOS.[4] While the first generation of inexpensive Android and iOS (iPad) tablet computers was available at the time this project was initiated, they cannot run ArcPad; plus, a key point of the study was to avoid purchasing an additional device but rather to test the capability of a smartphone the forester is likely to already possess and carry. The broader choice available *today* for the mobile geospatial software (for iOS and Android phones or tablets) situates this present research as important for those foresters considering low-cost mobile data collection systems. Moreover, with the wider choice of mobile apps and smartphone form factors today, the findings of this study are widely applicable to all new smartphone-based data collection systems in a forestry context.

Although it was hoped the creation of customized software could be avoided, it soon became apparent that the forest stand tally (FST) data that the company is required to collect under Ontario regulation and which is presently done using a paper-based system cannot be captured using any existing commercial software apps. A simple timber-cruise app was therefore created using Microsoft Visual Studio 2005 IDE. The app allows the user to enter multiple plot data related to tree species, size class and condition, and site characteristics. To avoid the need for specialized training on the software, data entry fields on the smartphone display were designed to mimic the paper tally form currently being used. This eliminated the need for specialized training on the software (an additional user cost) and permitted comparative testing and evaluation of the smartphone process versus the paper-based one. The FST app allows the user to not only record the same data as the paper-based form, but also to perform automatically incremental (tally) counts of tree species, record the forest stand's geographic position by means of the smartphone's GPS, and implement their own specific data entry controls. Data collected through the FST app are saved on the

[3] http://resources.arcgis.com/en/collector/ for Android and iOS devices. Note that these require an active internet connection to work, they cannot as of April 2013 be used for data collection in an off-line mode. Future versions should allow off-line data collection.

[4] GIS Kit Pro for iOS is a full featured geospatial data collection app that works off-line and data interchangeable with common GIS software formats, see http://garafa.com/wordpress/all-apps/gis-pro.

device as a series of comma-separated-value (CSV) files which can then be read into a Microsoft Excel workbook by a custom visual basic for applications (VBA) program that compiles and automatically transforms the tally plot data into a finalized spreadsheet in the same format the company uses for reporting requirements.

The total cost of equipment and developing the additional forest tally software was approximately $1,200 CAD ($550 for smartphone and $650 for development), roughly one-third of the cost of proprietary PDA that might be used by foresters, and within the same price range as the combined purchase of a high quality GPS device and digital camera. Technology now available could reduce to under $200 CAD the cost of a smartphone running the Android OS which can make use of a large set of more recent freely available geospatial data collection apps.

Once the device and software were ready, a series of initial feasibility and actual field tests were conducted to: collect user's perceptions about various features and aspects of the smartphone GIS design, operation and performance; measure the effectiveness, efficiency and learnability of the smartphone process; and assess its performance under real-world operational conditions. The standard for comparison was the existing system of paper-based forms, stand-alone GPS device and digital camera being used by Mazinaw-Lanark Forestry in its day-to-day operations.

The initial feasibility tests were conducted by recruiting 12 undergraduate students from the University of Ottawa who had no prior familiarity with either system. Using a treed area on campus as a trial course, the students were given a series of tasks to perform that required them to collect and record tree stand composition and GIS data using both the smartphone and the paper-based systems. On the day of testing, each participant was given a brief overview of the test design and research objective, followed by a 15–30 min tutorial and a demonstration of how to operate the smartphone device and collect data using the installed software, GPS and digital camera. Participants were given paper instruction cards outlining specific GIS data (6 point features, 2 polyline features, and 2 data editing tasks) and forest stand data (tree species, tree size, and regeneration classification) to be collected. Participants collected data on the smartphone device, and then in a second round used traditional paper-based methods. During both rounds of data collection, the amount of time spent on task, the number of times participants required help for each task, and any system errors or malfunctions that occurred were recorded. Subsequently, the amount of time required to enter the data into the desktop GIS under each of the two systems was also recorded. Data entry errors were counted and classified. The forms of distributions of data collection times were unclear, given the small sample of 10 participants and 12 data entry tasks. Therefore, a nonparametric paired Wilcoxon signed-rank test was used to compare the average data collection times between the groups in both rounds of data collection when the average times for the digital and paper data collection rounds did not show clear practical differences. When a given average time for one round is only slightly different from the other's, finding a statistically significant average time difference can provide some confidence to conclusions that a small time difference in frequently repeated tasks could with accumulation be operationally relevant for various data collection methods in the long-run. After finishing all tasks, the student participants completed a questionnaire and were interviewed to capture their experiences and perceptions regarding the usability of

the system. The questionnaire was based on the Questionnaire for User Satisfaction model developed by Chin et al. (1988).

The spatial accuracy of the data gathered using the smartphone was compared with that of data gathered using a consumer-grade hand-held Garmin GPS receiver. Participants in the initial feasibility tests were given a list of eight specific objects to pinpoint and sequentially visit (and link) within the test course area, first using the GPS device and then the smartphone. The positional accuracy of each device was identified following the method of Mitchell (2005). The GIS point and line data recorded by each device were mapped, with the values for the first, second, and third order standard distance deviations plotted as concentric circles for each point feature, and with each circle equal to the radius of the standard distance.

The second stage of testing was to evaluate the performance of the smartphone-based system by having a professional silviculturist employed by Mazinaw Lanarak Forest Inc use it in the field under normal operational conditions. This was done over the course of several days in May 2012 in an active forest management unit in eastern Ontario. The field usability assessment was made on qualitative comments provided by the test user, whose use of the device was being observed and noted by an observer throughout.

Results

Data Collection and Processing Efficiency

In the student tests more time was required to collect GIS and forest stand data using a smartphone than using a combination of a handheld GPS, camera and paper-based forms. Students were asked to locate and record ‘stand data’ for 10 trees in the test area, and locate an additional 10 other non-tree features (including signs, park benches and waste bins) to test the GPS reliability. The mean time for a student to locate and record non-treespatial data was about 20 % faster using the paper-based system [at 00:18:20 (h:mm:ss)] as compared to 00:23:43 with using the smartphone GIS system. This 5 min difference in average collection time for non-tree features was statistically significant ($p < 0.005$). Students were able to record forest stand information approximately 10 % faster using the paper tally sheets as compared with the smartphone app (0:01:50 vs. 0:02:04 respectively), a difference that was also significant ($p < 0.01$) but in practical terms equated to only a few seconds difference. However, when it came time to transfer and process the field data into the desktop GIS database, the benefits of the smartphone-based system became clear. The spatial data collected via the smartphone could be transferred to the server database in approximately 30 s, as compared with an average time of approximately 30 min to manually transfer the data collected using the paper-based system. This time difference was statistically significant ($p < 0.001$). It took on average 2 min to transfer the forest stand composition data from paper tally sheets to the spreadsheet on the server; the smartphone was able to transfer these data in under 20 s. Overall, it took participants approximately 50 % less time to complete the entire process of data collection, transfer and processing using the smartphone as compared with the paper-based system.

Table 1 Usability performance measurements for electronic and paper systems

User or device errors	Percent of participants that experienced malfunctions or committed data entry errors during GIS data collection	
	Electronic	Paper
Errors: data missing or entered incorrectly	100	50
Difficulty with ArcPad/GPS/camera GUI	42	0
Non-critical malfunction: ArcPad/GPS/camera not functioning properly	17	0
Critical malfunction: ArcPad/GPS/camera not function properly. Redo task	17	0
Experienced 2 or more malfunctions for a given task	58	0
Forest stand data errors		
Number of participants that entered incorrect forest stand data	1	0
Total number of data entry errors	6	0

Accuracy of the GIS Data

The spatial data recorded with the handheld GPS were more accurate than those collected with the smartphone. The mean distance of the observation recorded by participants from the estimated centre of each feature was 6.1 m using the GPS device as compared with a distance of 9.4 m when using the smartphone GIS. Polyline data generated from the GPS device also had greater positional accuracy than smartphone-collected polyline data.

Data Errors and Malfunctions

Participants in the simulation study were twice as likely to make a data entry error using the smartphone as compared with the combined paper-GPS-camera system. Participants did not experience any malfunctions or general technical problems with the GPS device or digital camera, but each participant experienced some technical difficulties or device malfunctions when using the smartphone (Table 1).

User Satisfaction

All participants were able to use each of the systems to carry out the trial exercises successfully. In the post-trial questionnaire and interviews, participants generally reported finding that both systems were easy to learn and use. Participants reported that entering information and selecting features on the touch screen was at times difficult. Half of the participants indicated that some tool buttons were too small to press easily or that a tool button did not respond well to user input on the smartphone touch screen. Faint backlighting of the display screen was another reported challenge. Participants preferred carrying a single smartphone device during data collection as compared with the need to tote a clipboard, GPS device

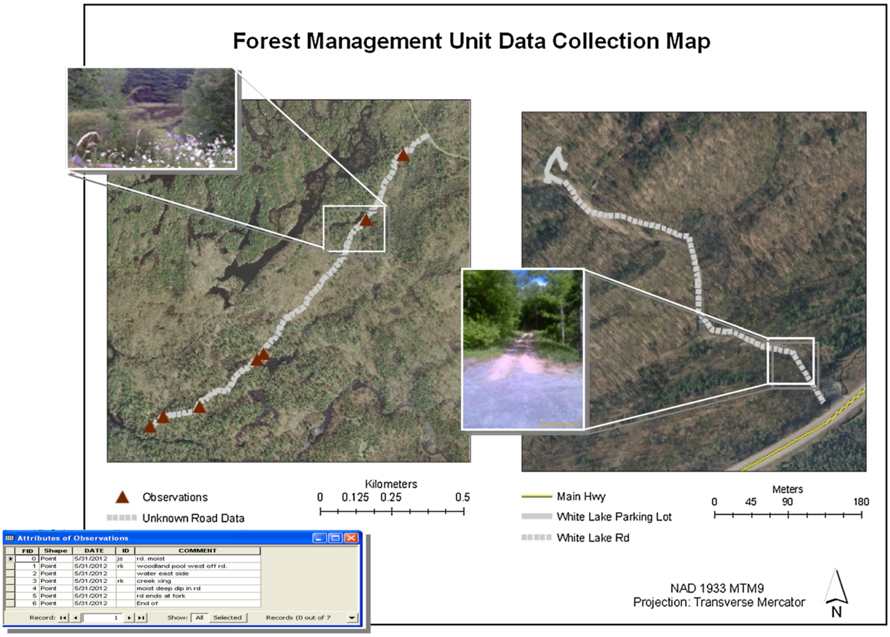

Fig. 2 Example of mapped smartphone GIS data taken during field testing

and camera, and generally preferred the automated features of the smartphone. One-quarter of the participants felt that data entry on the smartphone was faster than with the paper-based system, even though measurements did not support those perceptions.

Performance Under Real-World Conditions

Field testing of the smartphone was done by a Mazinaw Lanark Forestry silviculturist who already used the paper-based system on a regular basis. Over the course of several days the smartphone was used at several different sites in an actively managed mixed deciduous-coniferous forest outside the range of wireless reception. The activities performed included those regularly performed in the ordinary course of work, as well as experiments with ad hoc collection of data that the user believed would be helpful to record but could not easily be done with the existing paper-based system. An example of the latter is the ability to automatically associate photographs with feature class data for subsequent analysis.

In the field, the hardware and software functioning proved inconsistent. The mapping software was generally reliable, and the device was particularly adept at capturing ad hoc data (for an example see Fig. 2). On some occasions, GIS data that the operator collected was lost; however, this was mainly due to operator error and not the malfunctioning of the hardware or software, the most common being forgetting to periodically save data that had been recorded before initiating some other event with the software. Although the GPS accuracy of the smartphone had

been shown in the simulated trials to be roughly three meters less accurate than a dedicated GPS device, the field tester found the smartphone's accuracy to be acceptable for the nature and type of data collection for which it was being utilized. The capacity of the mobile ArcPad software to display various types of GIS data types (such as raster imagery) at the user's location was also found to be very useful.

The ability of the smartphone's forest stand app was found to be preferable for its ability to record information for several forest stands and plots in a consolidated format, as compared with making records on many paper sheets. The ability to maintain plot specific data and automatically record the user's geographic location for each plot was a key advantage over the traditional paper tally forms used by the forester. The electronic system allowed for plot data to be disaggregated during processing, thereby allowing for a more refined spatial analysis of plot dynamics. This is relevant, given that different parts of a sample stand or plot, or different species within it, may exhibit characteristics or behaviour over time that the silviculturist may wish to track separately from the plot as a whole. On one occasion, the forest stand app software completely ceased functioning early in the data collection process, and all previously recorded data about that plot was lost. This malfunction was later fixed by reloading the software onto the mobile device and no further errors occurred in subsequent testing. However, this malfunction reduced the user's confidence in the app, leading to the obvious conclusion that the software was less reliable than paper and pen. The silviculturist found the small screen size and faint or dim display in direct sunlight to be bothersome at times, though neither prevented collection of field data nor were they felt to be a limiting factor in the overall effectiveness of the smartphone system.

Discussion and Conclusions

Results of this research suggest that both the smartphone and the existing paper-based system have strengths and weaknesses. These can be discussed in terms of the up-front costs of creating a smartphone-based system, their comparative efficiency and usability, and a range of broader considerations.

The up-front costs include the absolute costs of the equipment and the investment of time to learn the electronic system and train employees on its use. The total out-of-pocket expense for purchasing the smartphone we selected and to develop the FSTapp totaled CAD $1,200. This amount does not include costs for the ESRI software or the desktop PC, which were already in use by the forestry company. The system architecture chosen for this project was based on the assumption that even small forestry companies will already possess some form of enterprise mapping software, office software, and desktop computing capacity similar to those tested. It was also assumed that a company's employees will already carry a smartphone. In other words, the only additional purchase costs for the smartphone system were the several hundred dollars spent to sub-contract the creation of the customized FST app. For small scale forestry operators who do not already use GIS software, a growing number of low cost or free alternatives exist to purchasing commercial,

licensed mapping software, or creating custom cruise applications (for example, GISKit Pro for iOS, open-source Quantum GIS for Android and Windows, and the USDA Forest Service's FScruiser software).

Creating the user-specific system, testing it, and training users all entail much greater up-front costs than the actual hardware and software purchases. It took one full-time research team member several weeks to construct the system architecture, to customize the ArcPad software to suit the company's data collection needs, and to test the custom mapping and forest stand software and their compatibility with the existing GIS system before trials could begin. A small scale forestry operation that does not possess such time and expertise in-house may therefore need to subcontract such tasks externally, and thereby incur significant financial costs. This in itself is likely to present one of the greatest barriers to moving from a tried and tested existing system, however less efficient it may be. However, once the smartphone based system had been developed, learning to use it and training others to do so proved to be less onerous than expected. Participants in the initial feasibility tests, who had no prior experience with either system and had no background in forestry, found the smartphone system to be generally intuitive and easy to use. Users did have to be re-shown how to use features of the smartphone (although this was also true of the handheld GPS device), suggesting that additional training and familiarization exercises (we estimate 90 min or more) would have been helpful. Depending on the number of employees who would have to be trained to use a smartphone-type system, this may represent another significant up-front investment that would need to be taken into account.

The usability, efficiency, and reliability of data collected using a smartphone present important considerations for any small scale forestry operator contemplating a smartphone-based field data collection system. Users in simulated tests and in the field found that while the software was relatively easy to operate, the small screen size and poor backlighting presented physical challenges. In the case of lighting, this was more a question of awkwardness leading to poor visibility and contrast, but the screen size may have contributed to the higher data entry error rate experienced by testers using the smartphone. Selecting point data on the small screen and activating small tool buttons was difficult for some users, with the resulting slow or unresponsive toolbutton commands possibly leading to errors and to spending extra time on some tasks. Such complaints may, however, become less of a concern with the increased screen size, resolution and processing speeds of smartphones introduced to the market since we conducted this study. The size distinction between large-display smartphones and small-display, wireless-enabled tablets is becoming increasingly blurred, and so future potential adopters will find a much larger array of suitable hardware choices and apps than were available when we began this study.

Even eliminating errors attributable to hardware, the error rate experienced in the field trials was greater for the smartphone. Many errors committed during testing were due to participants either omitting or not entering attribute data exactly as they were instructed. Such errors are not trivial, since data inaccuracies under real world conditions could lead to unreliable estimates of the harvestable wood supply or potentially affect protected wildlife habitats and other forest resources. However,

given the relative haste with which our participants were trained in using the smartphone and the relatively short duration of the trial period, it is likely that the user-induced error rate could be significantly reduced when the smartphone is used regularly, and if more stringent data entry controls are built into the software itself. Whether the error rate could be pushed down to the same level found within an existing paper-based system would need to be the subject of further study.

Trial users were able to record data between 10 and 20 % faster on paper with the aid of a GPS device and a camera, a difference that in absolute time amounted to a few minutes at most. We observed that as users became more familiar with the smartphone, their speed of data collection began to increase, and with repeated use we expect the differences between the two systems would become negligible. The most obvious benefit of the smartphone system is that once the data has been entered it is automatically converted into the appropriate electronic format for its intended end use. The field data does not need to be transmitted to the server in real time, but can be stored within the smartphone until the user has a wireless connection or is back in the office and is able to initiate the transfer of data to the GIS server. Depending on the volume of data and the speed of connectivity, the time consumed can be measured in seconds or at most, a few minutes. By comparison, even a relatively small amount of field data collected over the course of an hour or so required a full half-hour of office time to be manually entered into the server afterwards. The manual entry of data into the GIS server introduces potential transcription errors that do not plague the smartphone system. Depending on absolute labour costs and the opportunity cost of having staff performing non-value-added tasks, the efficiency savings alone may warrant closer consideration of the smartphone option by many small scale operators.

The smartphone allows the user to collect electronically opportunistic ad hoc data about the forest management unit, data that may be difficult or impossible to capture with other systems, and which may have long term value to the operator. For example, the images and data shown in Fig. 2 above were collected as supplemental information during routine testing of the smartphone system. While unplanned, this data was later used by the forestry company to update its 'areas of concern' GIS dataset, and that data was in turn used to advise field workers to exercise caution when operating in the area due to the presence of sensitive aquatic habitat. While this research tested a one device-one server system, the architecture could be scaled up to a distributed system synchronized to multiple smartphones, allowing users to transfer data beyond the destination server, facilitating real time data sharing. Using this particular example, in a distributed system the information about the presence of sensitive aquatic habitat could be shared with environment agencies and the general public to keep others from disturbing the area.

With regard to perceptions, participants in the simulations and field trials all preferred being able to use a single, familiar device over lugging around a combination of clipboards, cameras and GPS devices. The accuracy of the smartphone's embedded GPS is sufficient for those requiring accuracy to within a few meters, and the quality of the geo-referenced photos taken by the smartphone are such that it eliminates the need for a separate digital camera. In other words, there is no critical loss in data accuracy in

using the smartphone alone.[5] The ability to immediately convert observed data to electronic format was also seen as desirable by all participants and likely contributed to users' opinion. By contrast, the one malfunction that occurred during field testing and which resulted in the loss of a relatively small amount of data was enough to undermine the forester's confidence in the smartphone relative to the familiar paper-based system. Of course, paper forms can also be lost or damaged and the data lost, but nonetheless, the professional user must be fully confident that the smartphone system is failure-proof if it is going to be embraced. The need to spend extra hours manually entering data at the office may be for some a reasonable trade-off when compared with the possibility that the forester must return to a remote location because data recorded on a previous visit has been lost. This highlights the need for front-end investment in training and system testing before it is adopted for operational use.

In forestry as in any other industry, the acceptance and adoption of new technology is influenced by the belief that it will not pose any excessive time, energy or effort to learn in order to realize the benefits from its use (Davis 1989). Regardless of the potential for smartphones to improve field data collection, the reality is that employing mobile computing methods is not straightforward (as also noted by Park and Chen 2007). Small scale forestry operators typically have or face limited financial and labour resources, tough competition from larger operators, profit margins that are being continually squeezed, and expanding regulatory requirements. The productivity gains and additional value-added time that are possible from adopting mobile electronic data collection systems are tempting in such an environment. Our study has shown that such gains are indeed potentially realizable using smartphone devices that many operators already possess. The continually expanding array of smartphone and wireless-enabled tablet devices, as well as new spatial data software for use on mobile platforms, increases the number of potential opportunities to be explored. However, factors specific to each particular operator and operational jurisdiction, mean that a one-size-fits-all solution suitable for large numbers of small scale forestry operators does not presently exist. Even off-the-shelf technologies will require a considerable amount of tailoring to meet an individual operator's needs, and considerable investment relative to the size and revenue streams of small scale operations will be necessary. Despite these considerable challenges, our study suggests small-scale forestry operators will want to consider these types of systems, and that additional research is warranted, especially in other operating environments. We particularly believe that small scale forestry in developing regions could benefit from smartphone-based management systems, and highly encourage other researchers to explore such an avenue.

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[5] The smartphone's accuracy, transaction speed, and user satisfaction were not compared against proprietary personal data assistant devices that are commercially available and tailored for professionals who collect field data out of doors. It is likely the latter would be of greater accuracy, while their data transfer and processing speeds would depend on their compatibility with the user's server-based system. However, the principal research objective was to compare the smartphone a forestry worker might already be carrying with an existing system that was already in use in the study area.

developing mobile technology for data collection. This article benefitted considerably from the comments of the editor and two anonymous reviewers.

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